STRONG MOTION STUDIES IN THE MINES OF KOLAR GOLD FIELDS

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ABSTRACT

Rockbursts are common phenomenon in mines during mining operations. A network of geophones was used to locate and assess the stability of mine workings. The important parameters needed to assess the damage potential and severity of a rockburst is its Richter's local magnitude. It was not possible from the records of geophone due to saturation effect. A strong-motion accelerograph has been installed and has recorded many rockbursts after closure of the mines. The Strong-motion accelerograms recorded due to rockbursts are therefore used to obtain a Wood-Anderson synthetic seismogram for getting accurate and reliable values of the local magnitudes. Using 100 typical strong motion accelerograms of rockburst in the mines of Kolar Gold Fields, the magnitudes have been computed. The maximum magnitude obtained from several rockbursts during the period has been found to be 4.29. Attenuation relationships for peak horizontal ground acceleration for short distances and low magnitudes have been used for the development of the attenuation relationship. Two step multi regressions have been made by analyzing the decay of individual magnitude classes with distance using it with the whole data set. The models used in the present study is

$$\log(A)=c_1 + c_2 M - c_4 b \log(X+e^{c_3 M}) \qquad (1)$$

where A is the peak ground acceleration, X is the hypocentral distance, M is the local magnitude M_L and c_i's are regression coefficients. The discussions of the attenuation characteristics of the ground motion at shorter distances and low magnitudes have been discussed. The comparison of strong ground motion at similar distances using relationships developed from higher magnitudes reveals the difference in the observed peak ground horizontal accelerations with respect to the strain levels involved in the generation of the respective earthquakes.

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OBJECTIVES

The objective of this study is to use strong motion data to estimate the Richter's local magnitude and obtain attenuation relationships for peak horizontal ground acceleration for short distances and low magnitude in the mines of the Kolar Gold Fields.

RESEARCH ACCOMPLISHED

A rockburst is defined as the sudden and some times violent release of accumulated energy when a volume of rock is strained beyond its elastic limit (Scott et al., 1997). Bennett et al. (1997) defined rockbursts more broadly as "any type of stress-release phenomenon which has been induced by mining activity and which results in the emission of seismic signals." Rockburst is a common phenomenon since the beginning of the 20th century in the mines of the Kolar Gold Fields, which is situated in Karnataka. Rockbursts have caused severe damages to buildings on surface and underground mine workings in several instances. One of the important parameters needed to assess the damage potential and severity of a rockburst is its Richter's local magnitude. However, it has not been possible from the records of conventional seismographs due to saturation effect. The rockbursts had been monitored using a seismic monitoring system since 1979. The Strong Motion Accelerograph has been able to record several rockbursts as it is in the close vicinity of the mines of the Kolar Gold Fields, which has formed the basis for the estimation of their local magnitudes.

The Richter's local magnitude of a seismic event is defined in terms of the maximum amplitude of the record on a standard Wood-Anderson seismograph (WAS) with a natural period of 0.8s, damping ratio of 0.8 of critical damping, and static magnification equal to 2,800 (Richter 1958, 1935). If A is the maximum trace amplitude in millimeters on a WAS at an epicentral distance of R km, the local magnitude ML is given by $\log A - \log A_0(R)$, where $\log A_0(R)$ is a correction factor for the attenuation of seismic waves with distance. For distances less than about 25 km, the standard WAS normally goes out of scale even for small-magnitude events. Therefore, several investigators (e.g., Trifunac and Brune, 1970; Kannamori and Jennings, 1978; Luco,1982; Uhrhammer and Bolt, 1991; etc.) have proposed to evaluate the local magnitude by synthesizing the response of WAS using Strong Motion accelerograms. Due to short distances for recording of strong-motion data, their use for computation of magnitude has the advantage that they are not much influenced by the propagation path effects.

To estimate the local magnitude using synthesized WAS records, Trifunac (1991) proposed a method based on the frequency dependent attenuation function due to Trifunac and Lee (1990), which has been used and found to be more suitable in several applications (Lee, 1991; Gupta and Rambabu, 1993, etc.). However, Richter's original definition only has been considered suitable for the estimation of magnitudes in the present study.

India has faced several devastating earthquakes in the past. The largest of these have originated in the Himalayan plate boundary region, which has remained a region of great scientific and engineering interest. Not surprisingly, considerable data and earthquake related literature are available about the northern part of India. On the other hand very little seismological information is available about Peninsular India (PI); this is taken here as south of 24◦ N latitude. This situation is changing, in response to the three recent devastating events: the Khillari (30.9.1993), Jabalpur (22.5.1997), and Kutch (26.1.2001) shocks. But the available quantified information is so sparse, engineers presently face a daunting problem in estimating ground motion levels for future events in PI. The present paper is motivated by this need, to have a simple approach to understand attenuation in PI from the engineering point of view. First, the database available from Kolar region is briefly reviewed.

Peninsular India

The region of the Indian subcontinent south of 240N latitude is taken here as Peninsular India (PI). This landmass is far away from the Himalayan collision zone, which is a well known boundary between the Indian and the Asian plates. Nonetheless, it is recognized that Cambay and Rann of Kutch in Gujarat are among the very active regions of India. Leaving this region and the Andaman-Nicobar Islands, the remaining part of continental PI has reliably experienced some 400 earthquakes in a period of 600 years. This number will be much larger if all instrumentally recorded shocks of small magnitudes were also included. The seismicity of PI, from a seismological perspective has been discussed in the past notably by Chandra (1977), and Rao (1984). A catalogue of earthquakes of magnitude ≥ 3 for PI has been compiled by Guha and Basu (1993). Seeber et al. (1999) have studied the seismicity of PI with particular reference to Maharashtra. They concluded that between 1960 and 1990 the seismicity of PI showed a

threefold increase. This was the period during which industrial development also increased several fold in PI. Thus, engineers have to recognize that the looming seismic risk to man-made structures in PI is more than what was previously believed.

Seismological Model

In regions lacking strong motion data, seismological models (Boore 1983) are viable alternatives and are used worldwide for deriving attenuation relationships (Atkinson and Boore 1995, Hwang and Huo 1997, Toro et al. 1997). Singh et al (1999) have used a seismological model for estimating ground motion in parts of PI, but no specific attenuation equation has been proposed by them. The theory and application of seismological models for estimating ground motion has been discussed in detail by Boore (1983; 2003).

The Methodology

To use the strong-motion accelerograms for computing the local magnitude, it is necessary first to synthesize the response of the WAS with a given accelerogram as input excitation. The WAS can be modeled as a single-degree-of-freedom system with natural period Tn=0.8s, fraction of critical damping ζ=0.8 and static magnification Vs=2800. Thus, the displacement record, $x(t)$, of a WAS to a horizontal ground acceleration, $\ddot{z}(t)$, can be obtained by solving the following equation of motion:

$$\ddot{x}(t) + 2\zeta\omega_n\dot{x}(t) + \omega_n^2 x(t) = -V_S\ddot{z}(t)\,, \qquad (2)$$

where $\omega_n = 2\pi/T_S$ is the angular natural frequency of WAS. This equation has been solved using the algorithm due to Nigam and Jennings (1968) to compute the Wood-Anderson seismogram and to get its peak amplitude, $A_{synthetic}$, in millimeters. Figure 1 shows a typical example of the computed WAS seismograms along with the corresponding input strong-motion accelerograms. The magnitudes from the strong motion records are estimated using $A_{synthetic}$ as follows:

$$M_L^{SM} = \log A_{synthetic} - \log A_{\mathbf{0}}(R)\,, \qquad (3)$$

where $\log A_0(R)$ is the Richter correction factor for recording at distances other than 100 km, and basically represents the attenuation of seismic waves with distance.

Luco (1982) pointed out that the use of the Richter's correction factor $\log A_0(R)$ is, in general, not suitable to describe the attenuation of strong-motion amplitudes in the near field, particularly near 20 km. He, therefore, proposed a modification in the Richter attenuation function for smaller distances. Jennings and Kannamori (1983) also suggested similar modifications in $\log A_0(R)$ for small R, but their failure to include the local geological site effects in the analysis resulted in a biased estimate of this attenuation. However, Luco (1982) as well as Jennings and Kanamori (1983) have found these modifications to be insignificant at very short distances within about 5 km. Trifunac (1991) has shown that the peak values of the response of WAS may occur at different wave periods depending upon the source-to-site distance, magnitude, and the geological condition at a site. Therefore, using the frequency-dependent attenuation function due to Trifunac and Lee (1990) and the knowledge of the frequency where most energy is concentrated in the strong-motion as filtered by the WAS, he has defined an attenuation function $\mathrm{Att}(\Delta_0)$ in place of the Richter function, where Δ_0 is the hypocentral distance. This new attenuation function represents much faster decay of strong ground motion than the Richter's function for distances up to 35 km. Trifunac (1991) has also explained that the difference between the original Richter attenuation factor and $\mathrm{Att}(\Delta_0)$ is expected to approach zero at very small distances. In view of the above, the Richter attenuation factor is expected to be quite suitable without any modification or correction, as all the strong-motion data used in the present study are recorded within about 3.5 km of the epicentral distance. Figure 2 shows a typical rockburst recorded by the Strong Motion Accelerograph.

Results and Discussion

The methodology described in the above has been applied to compute the local magnitudes for 100 typical strong motion records obtained due to rockbursts in the Kolar Gold Field mines. All these events are distributed in all the

quadrants and distributed along the strike direction, which is in the north-south direction. The computed maximum amplitude of the synthesized Wood-Anderson seismograms and the corresponding strong-motion magnitudes are for both longitudinal and transverse components. The final magnitude is taken as the arithmetic mean of the magnitudes for both the components.

The distributions of the computed mean magnitudes are in the range between 0.67 and 4.68. It is seen that the available single station recording is able to record completely the rockbursts with a threshold magnitude of 2.0. This data can thus be of some predictive use by studying the temporal variation of b-value (Nuannin, 2006).

Attenuation

To work out the attenuation relation, as a first step, a linear regression analysis was carried out considering a simple relation. The attenuation of PGA with the distance was regressed to obtain the decay factor as given in the following equation. Figure 3 shows the plot of weak ground acceleration of rockbursts versus distance.

$$\log(A) = b \log(X) + c, \qquad (4)$$

where, A is acceleration, X is the hypocentral distance, and b and c are the regression coefficient.

Strong ground motions are usually recorded on three orthogonal components. In this study, we are dealing with horizontal components. One must decide how the horizontal components are to be treated. Various ways of treating a horizontal component are, the largest of the two components or both components or the mean of both components or vectorial combination of both components or a random selection of components.

A method of combining components should be taken into consideration to ensure consistency. However recent studies reveal to use geometric mean of two horizontal components. In this study, the geometric mean of two components (horizontal components) is calculated and used for the regression.

Data having hypocentral distances less than one is removed since there was a drastic change in PGA values for the recording having less than one kilometer hypocenter distance.

Dataset finally used for the regression is shown in Figure 3 below.

The events were classified according to the magnitude ranges as 2.00 < M < 2.20, 2.20 < M < 2.40, 2.40 < M < 2.60, 2.60 < M < 2.80, and 2.80 < M < 3.00. The individual decay factor, i.e., b, is given in Table 1. The average value of the decay parameter b came out to be 0.103

Table 1. B and C values computed using equation 2.

Magnitude Range	B	c
2.00 < M < 2.20	0.0360	0.724
2.20 < M < 2.40	0.1220	0.885
2.40 < M < 2.60	0.1280	1.100
2.60 < M < 2.80	0.0954	1.310
2.80 < M < 3.00	0.1350	1.520

Next, a general multiple regression analysis was performed for the whole data set by assuming the basic regression model as

$$\log(A) = aM - b \log(X) + c, \qquad (5)$$

where M is the magnitude and a, b and c are the regression coefficients. Using the above equation, the value of the decay parameter while considering the whole data set came out to be 0.1135 (0.0054), (The figure in the bracket is the standard error of coefficient) which is much closer to the average value of each earthquake, that is 0.1030.

The regression model thus selected for the attenuation relation is considered as follows:

$\log(A) = c_1 + c_2M - c_4\, b \log(X + \exp[c_3M]),$ (6)

Where c_1, c_2, and c_3 are the regression coefficients, and b is the decay parameter. When the decay parameter is fixed as per the regression using Equation 5, c_1, c_2, c_3, c_4 (and b) come out to be as shown in table below.

Coefficients	Value	Standard Error
c_1	-1.25430	0.0545000
c_2	0.93770	0.0162000
c_3	-3.1000	31.766500
c_4	34.9123	2040.3784
b	0.11350	0.0269000

From the regression it is found that the coefficient c_4 has a relatively larger error, so the regression is again carried out by removing coefficient c_4 and leaving the decay parameter b (renamed B) unconstrained. The results obtained are given in the table below. Figure 4 shows a typical earthquake recorded 100 km from the source to sensor.

Coefficients	Value	Standard Error
c_1	-1.3489	0.0280
c_2	1.0095	0.3820
c_3	0.1272	0.0689
B	0.1956	0.0183

Finally, the equation obtained is as follows:

$\mathbf{\log(a) = -1.3489 + 1.0095M - 0.1956\log(X + e^{0.1272M})}$

where '***a***' is in cm/sec^2. Standard deviation computed is 0.20.

CONCLUSIONS AND RECOMMENDATIONS

Local magnitudes have been computed for strong-motion accelerograms of seismic events in the mines of Kolar Gold Fields for the first time using the above procedure. The events selected are from an epicentral distance of 0.15 to 3.6 km from the place where the strong motion recorder is installed. The local magnitudes computed are in the range of 0.67 to 4.68.

The peak ground accelerations of rockbursts have been used to obtain the attenuation relation for short distances and low magnitudes. The final equation obtained is

$\mathrm{Log}(a) = -1.3489 + 1.0095M - 0.195 \log(X + \exp[0.1272M]),$

where **a** is in cm/sec^2. Standard deviation computed is 0.20.

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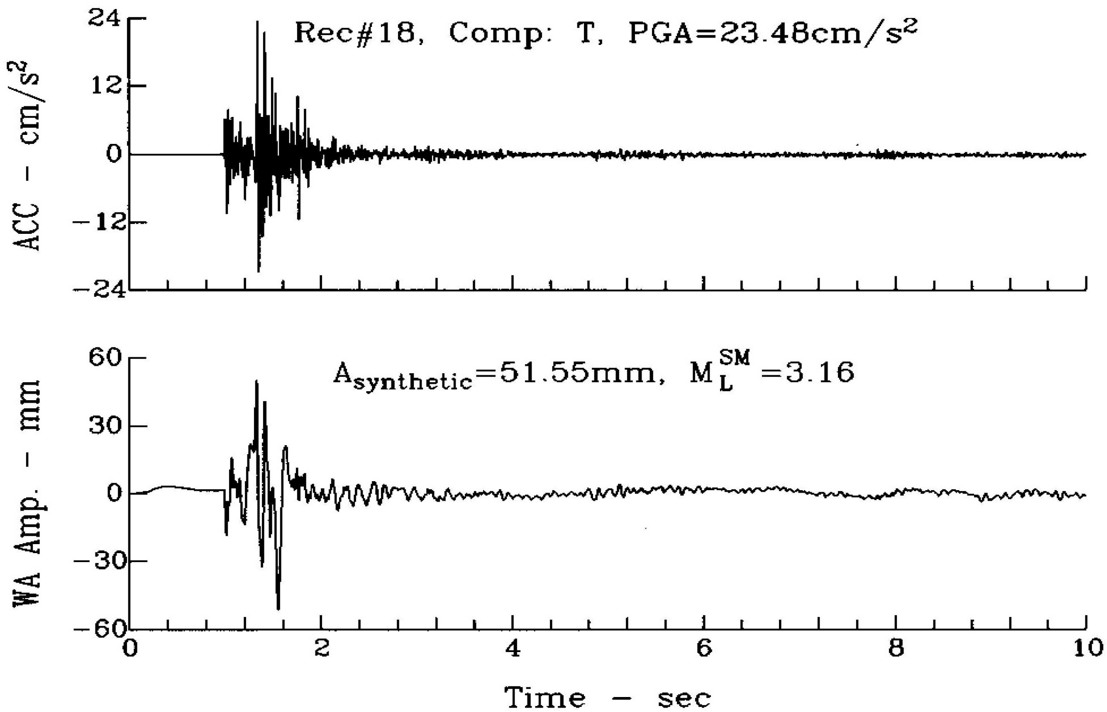
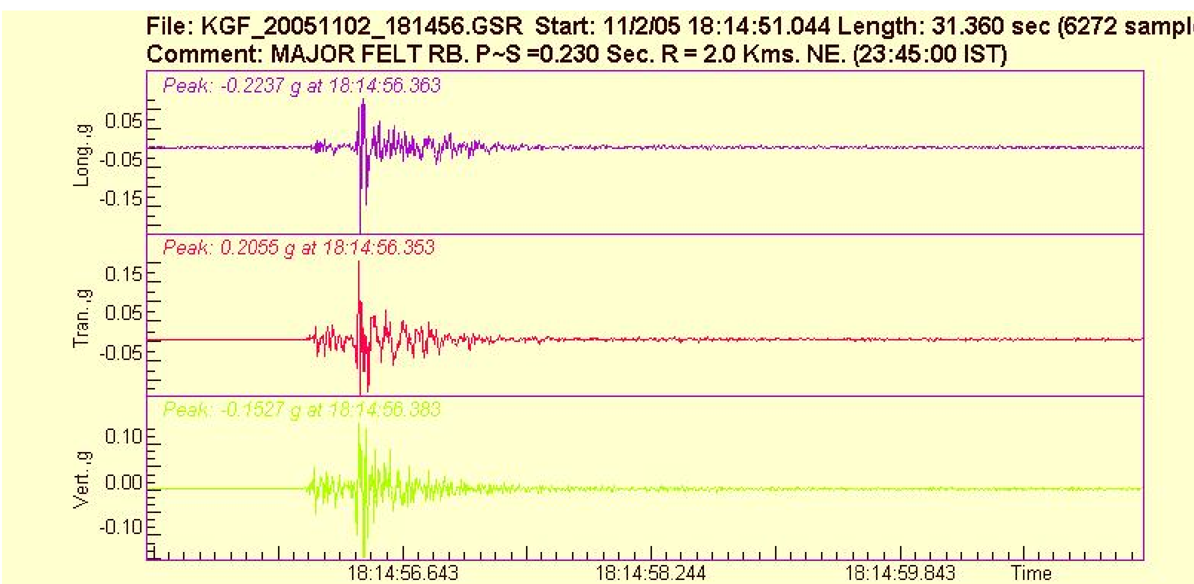


Figure 1. Typical examples of Wood-Anderson records synthesized from strong- Motion Accelerogram



record.

Figure-2. Typical rockburst recorded by strong motion accelerograph

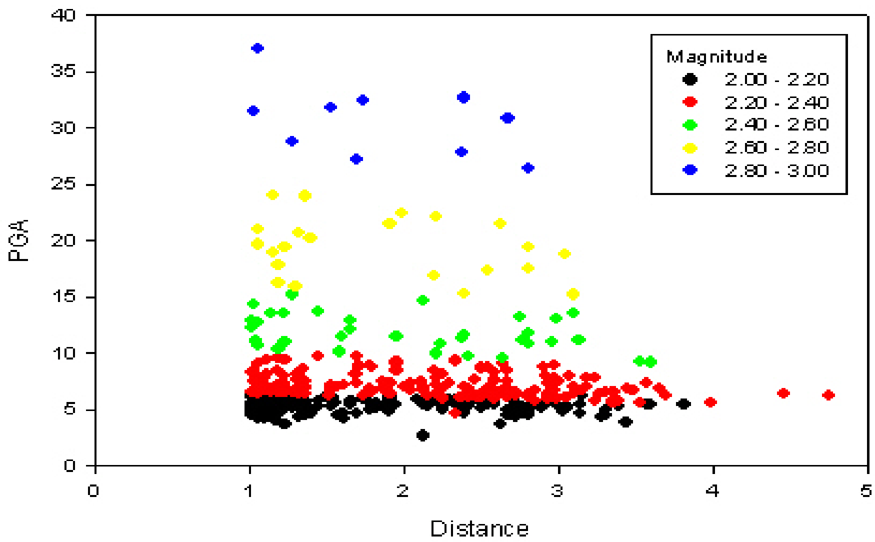


Figure 3. Plot of peak ground acceleration of rockbursts versus distance.

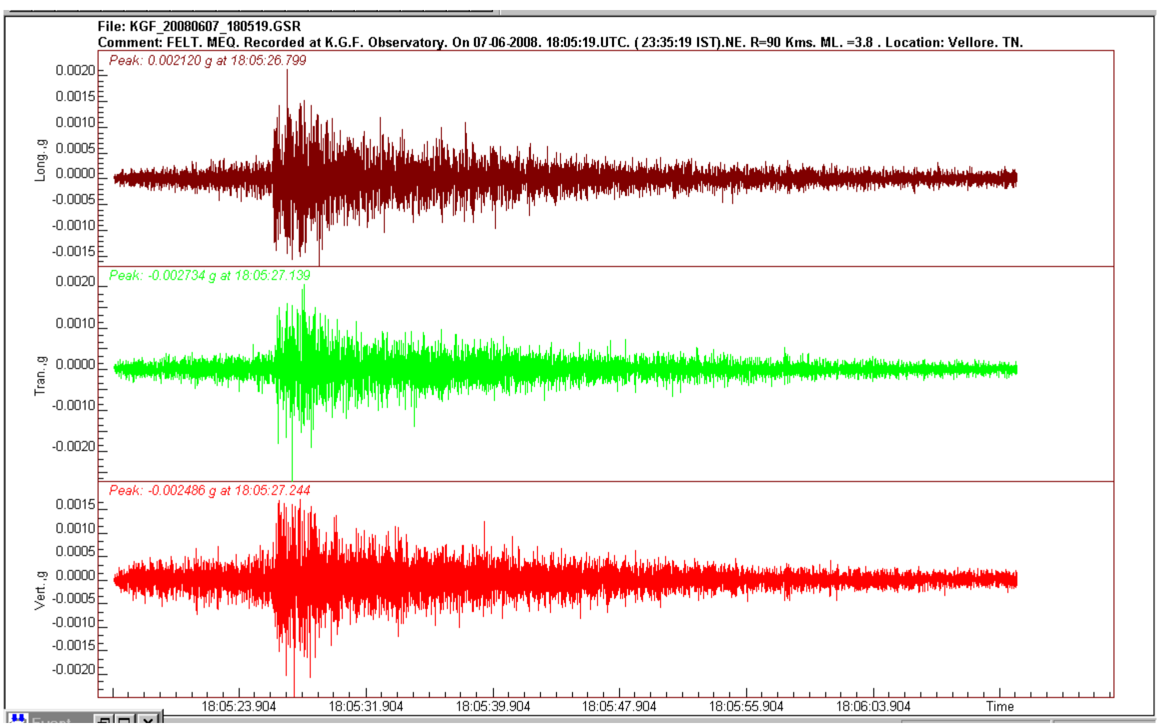


Figure-4. Typical earthquake recorded by Strong Motion Accelerograph